

**CATADIOPTIC PROJECTION SYSTEM FOR 157 NM LITHOGRAPHY**

**RELATED APPLICATIONS**

This application is a continuation of U.S. Patent Application Serial No. 10/444,897,  
5 filed May 23,2003, which is (1) a continuation of International Application Serial No.  
PCT/EP01/13851, filed November 28, 2001 and published in English on June 6, 2002, which  
claims priority from U.S. Provisional Patent Application Serial No. 60/253,508, filed  
November 28, 2000 and from U.S. Provisional Patent Application Serial No. 60/250,996, filed  
December 4, 2000, and (2) a Continuation-in-Part of U.S. Patent Application Serial No.  
10 09/761,562, filed January 16, 2001 (now U.S. Patent No. 6,636,350) which claims the benefit  
of priority to United States provisional patent application No. 60/176,190, filed January. 14,  
2000, all of the aforementioned patent applications and patents are hereby incorporated by  
reference in their entirety.

15 **BACKGROUND OF THE INVENTION**

**1. Field of the Invention**

The invention relates to projection systems for photolithography, and particularly to  
catadioptric systems including first and second optical imaging groups for 157 nm lithography.

## 2. Discussion of the Related Art

Extending DUV lithography to sub 100-nm linewidths requires a projection system with a high numerical aperture, e.g., 0.65-0.75 or larger, at a wavelength of 157 nm. As optical lithography is extended into the vacuum ultraviolet (VUV), issues surrounding the laser linewidth and material availability could cause substantive delays to the development of a commercial 157 nm step/repeat or step/scan tool. Therefore, it is desired to investigate optical configurations that minimize the consumption of calcium fluoride.

Microlithographic reduction projection catadioptric objectives, such as that shown and described with respect to Fig. 3 of European patent application no. EP 0 779 528 A2, which is hereby incorporated by reference, may be understood as variants of pure catoptric objectives. Fig. 3 of the '528 application shows a system having six mirrors and three lenses. The optical surfaces are generally symmetric to a common axis, and the object plane and the image plane are situated on this same axis upstream and downstream of the objective, respectively. As described in the '528 application, the system of Fig. 2 therein has a numerical aperture of only 0.55 and that of Fig. 3 therein only 0.6. In addition, all but one of the six mirrors shown at Fig. 3 are cut off sections of a bodies of revolution, yielding mounting and adjustment face difficulties. Also, the lenses shown in Fig. 3 serve only as correcting elements having minor effect. In addition, the most imageward (or optically closest to the image plane) mirror described in the '528 application is concave. It is desired to have an objective with a higher numerical aperture, and which is constructed for easier mounting and adjustment.



drawback since the size of this beam splitting element becomes quite large as the numerical aperture is increased up to and beyond 0.65 to 0.70, making the procurement of bulk optical material with sufficient quality (in three-dimensions) a high risk endeavor. This problem is exacerbated as wavelengths are driven below 193 nm because the selection of material that can be manufactured to lithographic quality is severely limited.

To circumvent this problem, it is recognized herein that it is desired to develop systems without beamsplitters. However, it is difficult to achieve an adequately high numerical aperture (e.g., U.S. patents 4,685,777, 5,323,263, 5,515,207 and 5,815,310, which are incorporated by reference), or to achieve a fully coaxial configuration, instead of relying on the use of folding mirrors to achieve parallel scanning (e.g., U.S. patent no. 5,835,275 and EP 0 816 892, which are incorporated by reference) and thereby complicating the alignment and structural dynamics of the system. In addition, it is desired to have an optical design that generally does not utilize too many lens elements, which can greatly increase the mass of the optical system.

WO 01/51 979 A (US ser. no. 60/176,190 and 09/761,562) and WO 01/55767 A (US ser. no. 60/176,190 and 09/759,806) - all commonly owned and published after the priority date of this application - show similar coaxial catadioptric objectives with 4 mirrors or more.

EP 1 069 448 A1 published after the priority date of this application shows a coaxial catadioptric objective with two curved mirrors and a real, intermediate image located besides the primary mirror.

All cited publications are incorporated herein by reference in their entirety. It is desired to develop a compact, coaxial, catadioptric projection system for deep ultraviolet and/or vacuum ultraviolet lithography that uses no beamsplitters or fold mirrors in its optical path.

5 It is an object of the invention to provide an objective for microlithographic projection reduction having high chromatic correction of typical bandwidths of excimer laser light sources, which permits a high image-side numerical aperture, and which reduces complexity with respect to mounting and adjusting.

### SUMMARY OF THE INVENTION

10 In view of the above, a photolithography reduction projection catadioptric objective is provided including a first optical group including an even number of at least four mirrors, and a second at least substantially dioptric optical group more imageward than the first optical group including a number of lenses for providing image reduction. The first optical group provides compensative axial colour correction for the second optical group according to claim

15 1. Other variations and preferred embodiments are subject of claims 2 to 26.

A preferred embodiment according to claim 11 is a photolithographic reduction projection catadioptric objective including a first optical group including an even number of at least six mirrors, and a second at least substantially dioptric optical group more imageward than the first optical group including a number of lenses for providing image reduction. This

20 increased number of mirrors gives more degrees of freedom to the correction and simplifies the design for stressed qualities.

## **BRIEF DESCRIPTION OF THE DRAWING**

Figure 1 shows the lens section of a projection objective for 157 nm photolithography according to a first preferred embodiment.

Figure 2 shows the lens section of a second preferred embodiment.

## **INCORPORATION BY REFERENCE**

What follows is a cite list of references which are, in addition to the references cited above in the background section, hereby incorporated by reference into the detailed description of the preferred embodiment, as disclosing alternative embodiments of elements or features of the preferred embodiment not otherwise set forth in detail herein with reference to Fig. 1 or

Fig. 2. A single one or a combination of two or more of these references may be consulted to obtain a variation of the preferred embodiment described above. Further patent, patent application and non-patent references, and discussion thereof, cited in the background and/or elsewhere herein are also incorporated by reference into the detailed description of the preferred embodiment with the same effect as just described with respect to the following

references:

U.S: patents no. 5,323,263, 5,515,207, 5,052,763, 5,537,260, 4,685,777, 5,071,240, 5,815,310, 5,401,934, 4,595,295, 4,232,969, 5,742,436, 5,805,357, 5,835,275, 4,171,871, 5,241,423, 5,089,913, 5,159,172, 5,608,526, 5,212,588, 5,686,728, 5,220,590, 5,153,898, 5,353,322, 5,315,629, 5,063,586, 5,410,434, 5,956,192, 5,071,240, 5,078,502, 6,014,252, 5,805,365, 6,033,079, 4,701,035 and 6,142,641; and German patent no. DE 196 39 586 A;

and United States patent applications no. 09/263,788 and 09/761,562; and European patent applications no. EP 0 816 892 A1, EP 0 779 528 A2 and EP 0 869 383 A; and

“Design of Reflective Relay for Soft X-Ray Lithography”, J.M. Rodgers, T.E. Jewell, International Lens Design Conference, 1990;

5 “Optical System Design Issues in Development of Projection Camera for EUV Lithography”, T.E. Jewell, SPIE Volume 2437, pages 340-347;

“Ring-Field EUVL Camera with Large Etendu”, W.C. Sweatt, OSA TOPS on Extreme Ultraviolet Lithography, 1996;

“Phase Shifting Diffraction Interferometry for Measuring Extreme Ultraviolet Optics”,  
10 G.E. Sornargren, OSA TOPS on Extreme Ultraviolet Lithography, 1996; and

“EUV Optical Design for a 100nm CD Imaging System”, D.W. Sweeney, R Hudyma, H.N. Chapman, and D. Shafer, SPIE Volume 3331, pages 2-10

### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

A catadioptric projection system according to a preferred embodiment herein is  
15 schematically shown at Fig. 1 and includes two distinct optical groups G1 and G2. Group G1 is a catadioptric group including mirrors M1-M6 and lenses E1-E3, as shown in Fig. 1. An object or mask plane Ob is disposed to the left of group G1 in Fig. 1 or optically before group G1. Group G2 is disposed optically after group G1 and to the right of group G1 in Fig. 1. An



mirror M2. At M2, strong negative lenses E2/B3 are used in a double-pass configuration for inducing overcorrected (positive) axial chromatic aberration used to balance or correct an undercorrected (negative) axial chromatic aberration created by the strong positive optical power of group G2. With regard to lateral chromatic aberration, Fig. 1 shows an aperture stop AS in group G2 placed in a quasi-symmetric manner, allowing the Lateral chromatic aberration to be at least nearly self-corrected within group G2 itself. In practice, lateral chromatic aberration of a few parts per million (ppm) may be within tolerance within group G2 and can be corrected using slight asymmetry of the chief ray near the conjugate stop position at mirror M2.

By balancing aberration correction between G1 and G2, the monochromatic aberrations are corrected in such a way to leave the lens elements within G2 “unstressed.” The term “unstressed” is used to signify the fact that no steep ray bendings are used within G2 to promote high-order aberration correction. Both the chief and marginal rays exhibit this behavior. The fact that group G2 is “unstressed” is advantageous when manufacturing and assembly tolerances are considered in detail.

Overall, the system of Fig. 1 includes 6 mirrors and 13 lens elements in a coaxial configuration all coaxial to axis A. The design utilizes an off-axis field to enable ray clearance and allow the mask and wafer planes to be parallel. Lens element E1 of group G1 is used to make the chief ray telecentric at the mask plane. Group G1 forms a virtual image behind mirror M6, which is relayed by the dioptric group G2 to form a final image at the wafer plane.

**Table 1. System of Fig. 1 Performance Summary**

Parameter	Performance
Wavelength (nm)	157
Spectral band (pm)	0.5
Reduction ratio (R)	0.20
Field size (mm)	22 x 7 rectangular
Numerical aperture (NA)	0.75
RMS wavefront error (waves)	0.013 $\lambda$
Distortion (nm)	< 1 nm
PAC (ppm)	39.0 ppm
PLC (ppm)	0.0 ppm
Total track (mm) distance Ob - Im	1250
Front working distance (mm)	25.0
Back working distance (mm)	10.0
Blank mass (kg, estimated)	39.0

Table 1 shows that the monochromatic RMS wavefront error, distortion, and chromatic aberrations PAC - paraxial axial colour aberration and PLC - paraxial local colour aberration are reduced small residual values as desired for precision lithographic projection systems. Further, the system of Fig. 1 may be confined within a volume that is similar to or smaller

than conventional systems, meaning that the footprint of legacy tools can be maintained, if desired.

**Table 2: Optical Design Prescription for the System of Fig. 1**

RDY	THI	RMD	GLA
OBJ:	INFINITY	25.000000	
1:	INFINITY	0.000000	
2:	INFINITY	0.000000	
3:	329.41693	30.000000	'cafl_vuv'
ASP:			
K : 0.722126			
A : 0.000000E+00	B :- .225942E-11	C : 0.167998E-15	D : -.128550E-20
E : -.233823E-24	F : 0.685735E-29	G : 0.000000E+00	H : 0.000000E+00
4:	502.56913	59.208438	
5:	INFINITY	347.586957	
6:	-1183.47149	-347.586957	REFL
ASP:			
K :			
A :- .127089E-08	B : 0.812330E-14	C :- .123118E-18	D : 0.894383E-23
E :- .276494E-27	F : 0.402755E-32	G : 0.000000E+00	H : 0.000000E+00
7:	279.62176	-7.500000	'cafl_vuv'
8:	745.02111	-5.835889	
9:	350.74458	-7.500000	'cafl_vuv'
10:	1226.35940	-8.372549	
11:	324.93068	8.372549	REFL
ASP:			
K:0.069031			
A : -551054E-09	B :- .166403E-13	C :- .307699E-18	D : 0.277748E-22
E :- .680019E-26	F : 0.506026E-30	G : 0.000000E+00	H : 0.000000E+00
12:	1226.35940	7.500000	cafl_vuv'
13:	350.74458	5.835889	
14:	745.02111	7.500000	'cafl_vuv'
15:	279.62176	304.397688	
16:	490.28038	-244.852865	REFL
ASP:			
K : -1.803201			
A :- .482804E-08	B :- .125400E-12	C : 0.242638E-17	D :- .680221E-22

E :0.237919E-26	F :-.315262E-31	G :0.000000E+00	H :0.000000E+00
17:	667.70113	565.726496	REFL
ASP:			
K : -0.118347			
A : -.275181E-09	B :-.327224E-14	C :0.200875E-19	D :-.620470E-24
E :0.627048E-29	F :-.394543E-34	G :0.000000E+00	H :0.000000E+00
18:	INFINITY	25.997938	
SLB: "Intermediate image"			
19:	-1126.18103	-178.682300	REFL
ASP:			
K : 7.738777			
A : -.668802E-08	B :0.253685E-12	C :-.548789E-17	D :0.625386E-22
E : -.276305E-27	F : -120188E-33	G :0.000000E+00	H : -0.000000E+00
20:	-1002.36339	178.682300	REFL
ASP:			
K : 50.616566			
A : -973184E-08	B :0.308396E-12	C :-.511443E-16	D :0.428520E-20
E : -217208E-24	F :0.518418E-29	G :0.000000E+00	H :0.000000E+00
21:	INFINITY	-324.644282	
22:	INFINITY	324.644282	
SLB:"Virtual image"			
23:	INFINITY	139.926509	
24:	532.50558	30.000000	'cafl_vuv'
ASP:			
K : -28.969955			
A :0.000000E+00	B :-.109172E-11	C :0.625819E-16	D :-.274325E-20
E :0.634878E-25	F :0.581549E-29	G :0.000000E+00	H :0.000000E+00
25:	-584.92060	2.500000	
26:	1292.88867	13.668481	'cafl_vuv'
27:	-1383.77341	2.500000	
28:	760.97648	15.674455	'cafl_vuv'
29:	-1077.75076	11.001421	
30:	-250.22566	10.000000	'cafl_vuv'
31:	-500.99843	11.138638	
STO:	INFINITY	22.619203	
SLB: "stop"			
33:	-298.09900	18.822972	'cafl_vuv'
ASP:			

K : 6.689541			
A : 0.000000E+00	B : 0.346206E-12	C : -498302E-17	D : 0.272385E-20
E : -1.06617E-24	F : 0.175645E-28	G : 0.000000E+00	H : 0.000000E+00
34:	-1073.42340	0.500000	
35:	267.47103	50.000000	'cafl_ 'vuv'
36:	-607.58973	0.592125	
37:	258.51526	27.182889	'cafl_ 'vuv'
38:	-8945.70709	0.500000	
39:	159.70628	39.768717	'cafl_ 'vuv'
ASP:			
K : -1.214880			
A : 0.000000E+00	B : -.252828E-11	C : -.632030E-16	D : -.765024E-21
E : 0.477017E-24	F : -.163970E-28	G : 0.000000E+00	H : 0.000000E+00
40:	-746.03878	0.500000	
41:	122.36092	43.154424	'cafl_ 'vuv'
42:	95.77143	4.340799	
ASP:			
K : 1.012065			
A : 0.000000E+00	B : 0.214891E-12	C : -.187071E-14	D : -.681922E-18
E : 0.313376E-22	F : 0.000000E+00	G : 0.000000E+00	H : 0.000000E+00
43:	115.81595	30.082531	'cafl_ 'vuv'
44:	-1828.47137	9.930603	
IMG:	INFINITY	0.000000	

The catadioptric projection system according to a second preferred embodiment herein is schematically shown at Fig. 2 and includes two distinct optical groups G1' and G2'. Group G1' is a catadioptric group including mirrors M1'-M6' and lenses E1'-E3', as shown in Fig. 2.

5 An object or mask plane Ob' is disposed to the left of group G1' in Fig. 2 or optically before Group G1'. Group G2' is disposed optically after group G1' and to the right of G1' in Fig. 2. An image or wafer plane Im' is disposed optically after group G2' and to the right of group G2' in Fig. 2.

Group G1' functions by correcting field aberrations and providing a conjugate stop CS' position for correction of axial chromatic aberration. Group G2' is a dioptric group including

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lens elements E4'-E13', as also shown in Fig. 2. Group G2' lies aft of G1', or optically nearer the image plane Im' of the system, enabling the system to achieve numerical apertures in excess of 0.65, 0.70 and even 0.75. This catadioptric system achieves a high numerical aperture preferably using no beamsplitters nor fold mirrors. The description herein examines the performance of the second preferred embodiment of Fig. 2.

The first embodiment of Fig. 1 features independent correction of lateral chromatic aberration in the individual imaging groups. This feature influenced the optical construction in terms of stop position(s), element powers and element shapes. In the present second embodiment, the independent lateral color correction feature is not included and a balance of lateral color is struck between the fore and aft groups.

Group G1' is a catadioptric group that functions by correcting field aberrations and providing a conjugate stop position to correct axial chromatic aberration. Group G2' is a dioptric group that lies aft of G1' enabling the system to achieve numerical apertures(NA) in excess of 0.65, and preferably at least 0.70, or 0.75, or even 0.80 or higher. For example, a system in accord with the preferred embodiment may be configured to exhibit a NA of 0.79 while advantageously having a RMS wavefront error of only  $0.0115\lambda$ . That is, the system may be configured with a NA above 0.75, while maintaining the RMS wavefront error below  $0.02\lambda$ , and even below  $0.015\lambda$ .

The system shown in Fig. 2 has two distinct groups, as mentioned above. Group G1' includes an even number of at least four mirrors, and preferably has six mirrors M1'-M6'. Group G1' further preferably includes three lens elements E1'-E3'. Group G2' includes a lens

barrel of ten individual lens elements E4'-E13', as shown in Fig. 2. The design is coaxial having a single common centerline, respectively, of the system of two optical groups G1' and G2' shown in Fig. 2. The design uses an off-axis field to achieve ray clearances in group G1'. Since Group G2' is dioptric, ray clearance problems are eliminated enabling a system with a high numerical aperture. The concept also provides for unlimited scanning of the mask and wafer in a parallel configuration.

Group G1' of Fig. 2 forms a minified, virtual image VI' located behind mirror M6' at a reduction of  $\sim 0.8x$ . Group G2' relays this virtual image VI' to form a usable real image Im at the wafer. Group G2' operates at a reduction of about  $0.25x$ , allowing the system to achieve a reduction of  $0.20x$ . A complete optical prescription is found in Table 5 below, describing the optical surfaces in Code V format.

To correct chromatic aberration, the aperture stop AS' that lies in group G2' has a conjugate stop CS' position in group G1' between mirror M1' and M2'. This allows a negative chief ray height at elements E2' and E3' (for positive field height at the reticle (Ob')). This chief ray height, when combined with the sign of the marginal ray and the negative power of the E2'/E3' pair, provides for a lateral chromatic aberration contribution that substantially cancels the lateral color contribution from group G2'. Assuming a spectral bandwidth of  $0.5 \mu m$ , this specific embodiment has a paraxial lateral color contribution from E2'/E3' of  $\sim 35$  ppm, whereas the paraxial lateral color contribution from Group G2' is  $\sim 35$  ppm, resulting in an advantageous sum total of approximately 0 ppm. The principle result is that the power distribution and shapes of the lenses in group G2' take on a very advantageous form.

Figure 2 also specifically shows raytrace layout of the preferred embodiment. The system shown includes six mirrors M1'-M6' and thirteen lens elements E1'-E13' in a coaxial configuration. The design utilizes an off-axis field (ring field, rectangular slit field or the like) to enable ray clearance and allow the mask and wafer planes Ob', Im' to be parallel. Element E1 is preferably used advantageously to make the chief ray telecentric at the mask plane Ob', as described in more detail below. Group G1' forms a virtual image VI' behind mirror M6', which is relayed by dioptric group G2' to form the final image at the wafer plane Im'. A real intermediate image Im' is also formed between mirrors M4' and M5' of group G1', as shown in Fig. 2.

At mirror M2', negative lenses E2'/E3' are used in a double-pass configuration to induce overcorrected (positive) axial chromatic aberration used to correct undercorrected (negative) axial chromatic aberration created by the strong positive optical power of group G2'. The monochromatic aberrations are corrected via a balance between groups G1' and G2'. In addition, this is done in such a manner as to leave the lens elements E4'-E13' in group G2' "unstressed" as in the first embodiment.

Lens element E1' provides for the telecentric condition at the plane Ob' of the mask. It is advantageous to have positive optical power near the mask to reduce the chief ray height on mirror M1'. Lens element E1' appears to lie in conflict with the substrate of mirror M2'. To achieve this concept, it is preferred that only a small off-axis section of E1' be used. This means that pieces of a complete E1' could be sectioned to yield pieces for multiple projection systems, further reducing the required blank mass of a single system.

Another option to resolve the apparent conflict between lens E1' and the substrate of mirror M2' is to place lens E1' between mirrors M1' and M2', such as somewhere close to the group of lens elements E2'/E3'. In this Manner, the complete lens would be used.

**Table 3: Performance Summary of System of Fig. 2**

Parameter	Performance
Wavelength (nm)	157
Spectral band (pm)	0.5
Reduction Ratio (R)	0.20
Field size (mm)	22 x 7
Numerical aperture(NA)	0.75
RMS wavefront error(waves)	0.006 $\lambda$
Distortion (nm)	< 2 nm
PAC (ppm)	42.0 ppm
PLC (ppm)	0.7 ppm
Total track (mm)	1064
Front working distance(mm)	28.0
Back working distance(mm)	8.7
Blank mass (kg, estimated)	34.4



qualitative standpoint, the table reveals that the preferred embodiment herein scales well with numerical aperture. For example, the composite RMS only grows by  $0.005\lambda$  from  $0.0058\lambda$  to  $0.0115\lambda$  as the NA is scaled from 0.75 to 0.79. The results indicate that the system of the preferred embodiment may be scaled to a numerical aperture larger than 0.80.

5

**Table 5: Optical Design Prescription of System of Fig. 2**

RDY	THI	RMD	GLA
OBJ:	INFINITY	28.000000	
1:	INFINITY	0.000000	
2:	INFINITY	0.000000	
3:	256.21415	19.957583	'cafl_vuv'
4:	461.83199	42.954933	
5:	INFINITY	329.408468	
6:	-947.39721	-329.408468	REFL
ASP:			
K: 10.217685			
A: -.271423E-08	B :0.413774E-13	C :0.119957E-17	D :0.566939E-22
E: -.201485E-26			
7:	235.67059	-5.250000	'cafl_vuv'
8:	1202.79595	-18.801014	
9:	199.92931	-5.250000	'cafl_vuv'
10:	471.74620	-10.153919	
11:	245.63551	10.153919	REFL
ASP:			
K : 0.060091			
A :0.624853E-09	B :0.113020E-13	C :- .515404E-18	D :0.170604E-21
E = .159226E-25	F :0.105279E-29		
12:	471.74620	5.250000	'cafl_vuv'
13:	199.92931	18.801014	
14:	1202.79595	5250000	'cafl_vuv'
15:	235.67059	298.515259	
16:	490.36196	-227.868676	REFL
ASP:			
K : 0.133019			
A :-.401120E-08	B :- .925737E-13	C :- .236166E-17	D :0.108790E-21
E :- .551175E-26	F :0.127289E-30		
17:	611.66355	331.489215	REFL
ASP:			
K : -0.837736			



40:	29770.37524	2.727081			
41:	130.31599	33.479292		'cafl_vuv'	
42:	54.66735	3.097821			
ASP:					
K : 0.179565					
A :O.000O00E+00	B :0.129145E-I 1	C :-.283430E-14		D : .650118E-17	
E :0.238362E-20					
43:	108.48722	20.284450		'cafl_vuv'	
44:	INFINITY	8.741020			
IMG	INFINI11'	0.000000		q	
SPECIFICATION DATA					
NAO 0.15000					
TEL					
DIM	MM				
WL	157.63	157.63		157.63	
REF 21 1					
WTW	1	1		1	
XOB	0.00000	0.00000	0.00000	0.00000	0.00000
YOB	66.50000	75.25000	84.00000	92.75000	101.50000
YOB	1.00000	1.00000	1.00000	1.00000	1.00000
VUY	0.00000	0.00000	0.00000	0.00000	0.00000
VLY	0.00000	0.00000	0.00000	0.00000	0.00000
REFRACTNE INDICES					
GLASS CODE	157.63				
'cafl_vuv'	1.559288				
No solves defined in system					
INFINITE CONJUGATES					
EFL -21643.8522					
BFL -4320.0292					
FFL 0.1082E+06					
FNO 0.0000					
AT USED CONJUGATES					
RED -0.2000					
FNO -0.6667					
OBJ DIS 28.0000					
TT 1064.0000					
IMG DIS 8.7410					
OAL 1027.2590					
PARAXIAL IMAGE					
HT 20.3000					
THI 8.7412					
ANG 0.0000					
ENTRANCE PUPIL					
DIA 0.3034E+10					

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THI 0.1000E+11
EXIT PUPIL
DIA 6567.5310
TFil -4320.0760
SPECIFICATION DATA
NAO 0.15000
TEL
DIM MM
WL 157.63
REF 1
WTW 1
XOB      0.00000      0.00000      0.00000      0.00000      0.00000
          0.00000      0.00000      0.00000      0.00000
YOB      100.00000    107.50000    115.00000    125.50000    130.00000
          105.00000    110.00000    120.00000    125.00000
YOB      1.00000      1.00000      1.00000      1.00000      1.00000
          1.00000      1.00000      1.00000      1.00000
VUY      0.00000      0.00000      0.00000      0.00000      0.00000
          0.00000      0.00000      0.00000      0.00000
VLY      0.00000      0.00000      0.00000      0.00000      0.00000
          0.00000      0.00000      0.00000      0.00000
REFRACTNE INDICES
GLASS CODE      157.63
'cafl vuv'      1.559288
No solves defined in system
INFINITE CONJUGATES
EFL -521.5384
BFL -94.3531
FFL 2582.5092
FNO 0.0000
AT USED CONJUGATES
RED -0.2000
FNO -0.6667
OBJ DI5 25.0000
TT 1249.8815
IMG DIS 9.9306
OAL 1214.9509
P.SRAXIAL IMAGE
HT 25.0018
THI 9.9619
ANG 0.0000
ENTRANCE PUPIL
DIA 0.3034E+10
THI 0.1000E+11

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The optical design description provided herein demonstrates an advantageous catadioptric projection system for DUV or VUV photolithography. While the preferred embodiment has been designed for use in an 157 nm tool, the basic concept has no wavelength limitations, either shorter or longer, providing a suitable refractive material exists. Some features of the preferred system herein are summarized below.

### CONFIGURATION

The preferred optical system is catadioptric and includes two optical groups, group G1 and group G2, configured such that group G1 presents a reduced, virtual image to group G2.

The function of group G2 is to relay this virtual image to a real image located at the plane of the wafer. Group G1 preferably includes an even number of at least four and preferably 4 or 6 mirrors in combination with lens elements whose primary function is to provide telecentricity at the mask and enable correction of axial chromatic aberration. In the preferred embodiment, an image of the aperture stop is located in close proximity to mirror M2.

Group G2 is preferably entirely dioptric providing most of the system reduction and a corresponding high numerical aperture (in excess of 0.65, 0.70 and even 0.75) at the image. This group G2 also makes the final image telecentric in image space. Group G1 functions to correct high-order field aberrations, advantageously allowing a substantial relaxation of the lens elements found in group G2. Both group G1 and group G2 make use of aspheric surfaces as set forth in the Table 2. The same holds for the second preferred embodiment.

## **SYMMETRY**

The preferred optical design herein is co-axial, wherein each of the optical elements is rotationally symmetric about a common centerline. The preferred system advantageously does not utilize fold mirrors, prisms, or beamsplitters to fold the opto-mechanical axis. This enables a compact configuration and eliminates substantial bulk refractive material that may be difficult to procure in a timely manner.

## **PARALLEL SCANNING**

The preferred optical system herein achieves mask and wafer planes that are parallel, enabling unlimited scanning in a step/scan lithographic configuration.

## **CORRECTION OF CHROMATIC ABERRATION**

Correction of chromatic aberration is achieved preferably using a single optical material in the catadioptric configuration described herein. Lateral chromatic aberration is at least substantially self-corrected within group G2, using a balance of optical power on either side of a primary aperture stop located within group G2. Correction of axial chromatic aberration is enabled using a negative lens group E2/E3 located at mirror M2 in group G1, providing an axial chromatic aberration contribution that is nearly equal in magnitude and opposite in sign to the chromatic aberration generated by G2. This high level of axial chromatic aberration correction relaxes the need for a high spectral purity laser exposure source with linewidths on the order of 0.1 to 0.2 pm.

Some additional features of the preferred system herein are set forth below. The preferred system is an imaging system for photolithographic applications using 157 nm, 193 nm or 248 nm or other exposure radiation including first and second optical groups, or groups G1 and G2. The first optical group, i.e., group G1, is either a catoptric or catadioptric group including preferably six mirrors. Group G1 preferably also includes one or more lens elements, e.g., to make the chief ray telecentric at a mask plane and to correct axial chromatic aberration.

The second optical group, or Group G2, is a dioptric group of several lens elements for reducing and projecting an image to a wafer plane. Group G2 is preferably a relaxed group such that optical paths of projected rays are smoothly redirected at each lens element, e.g., less than  $45^\circ$  and preferably less than  $30^\circ$ , and still more preferably less than  $20^\circ$ , as shown in Fig. 1. This preferred system is contradistinct from a Dyson-type system which has one reflective component performing reduction of the image. In contrast to the Dyson-type system, the preferred system has a dioptric second group (group G2) performing reduction, while the catoptric or catadioptric first group (group G1) forms a virtual image for reduction by Group G2 and provides aberration compensation for group G2.

The first and second groups, or groups G1 and G2, respectively, of the preferred imaging system herein enable parallel scanning and a symmetric, coaxial optical design. Stops are located preferably at or near the second mirror M2 of Group G1 and within Group G2. The first stop may be alternatively moved off of the second mirror to enhance aberration correction.

